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(54) Optical device and reform fabrication

(57) A method of fabricating an optical device having a prescribed refractive index profile, comprises forming a surface with an initial refractive index formation and altering it by directing a laser beam onto the surface, either as it is formed or afterwards, so as to selectively evaporate material from a predetermined part of the surface. The refractive index profile of a growing soot form fabricated by the axial vapor deposition method is altered by evaporating the index modifying dopant from selected portion of the form. In an illustrative embodiment of the invention described, a laser beam (17) is used to "write" the desired pattern on the growing form (10). The technique can be employed to fabricate optical fiber preforms as well as two and three dimensional integrated optical devices and circuits.

FIG. 1

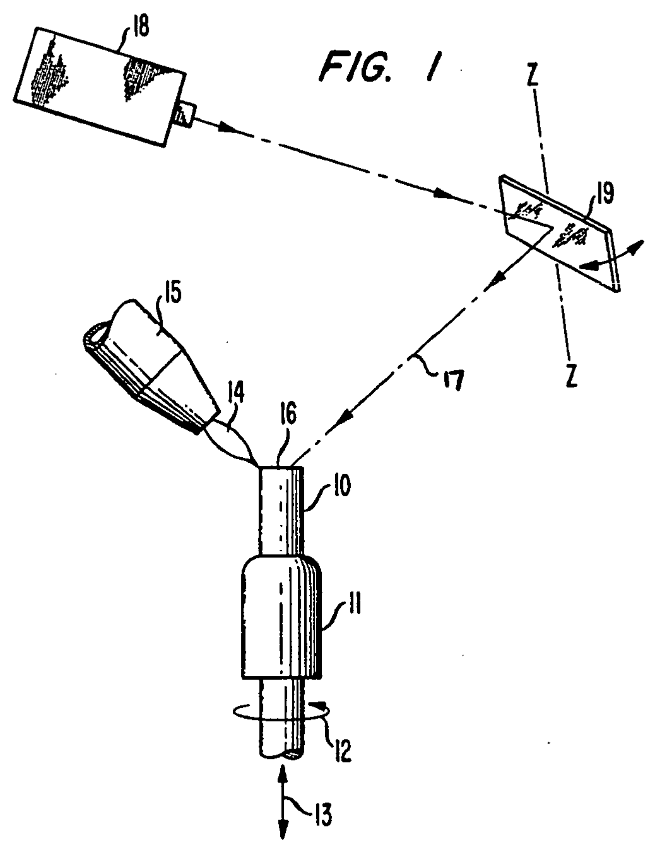

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FIG. 1

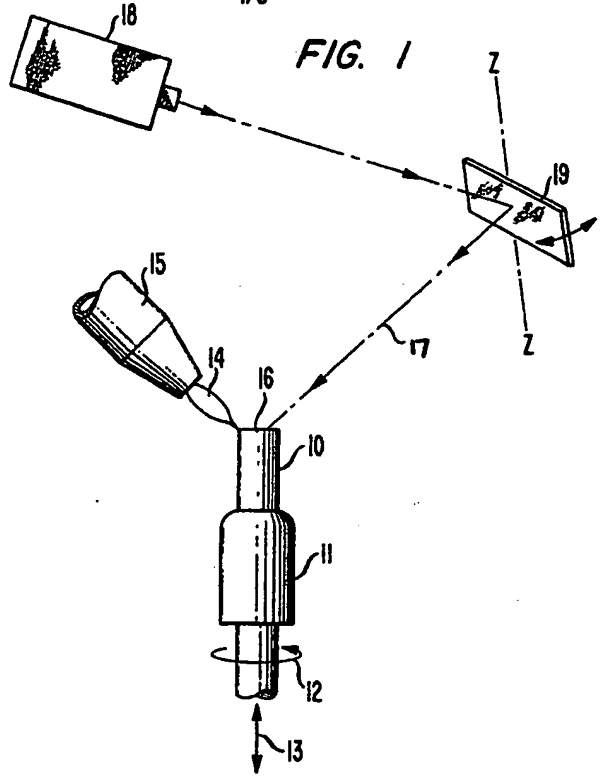


FIG. 2

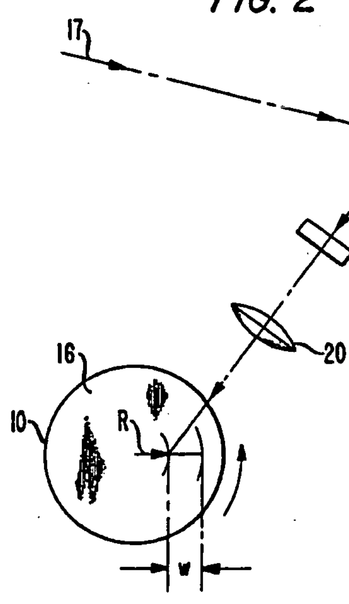
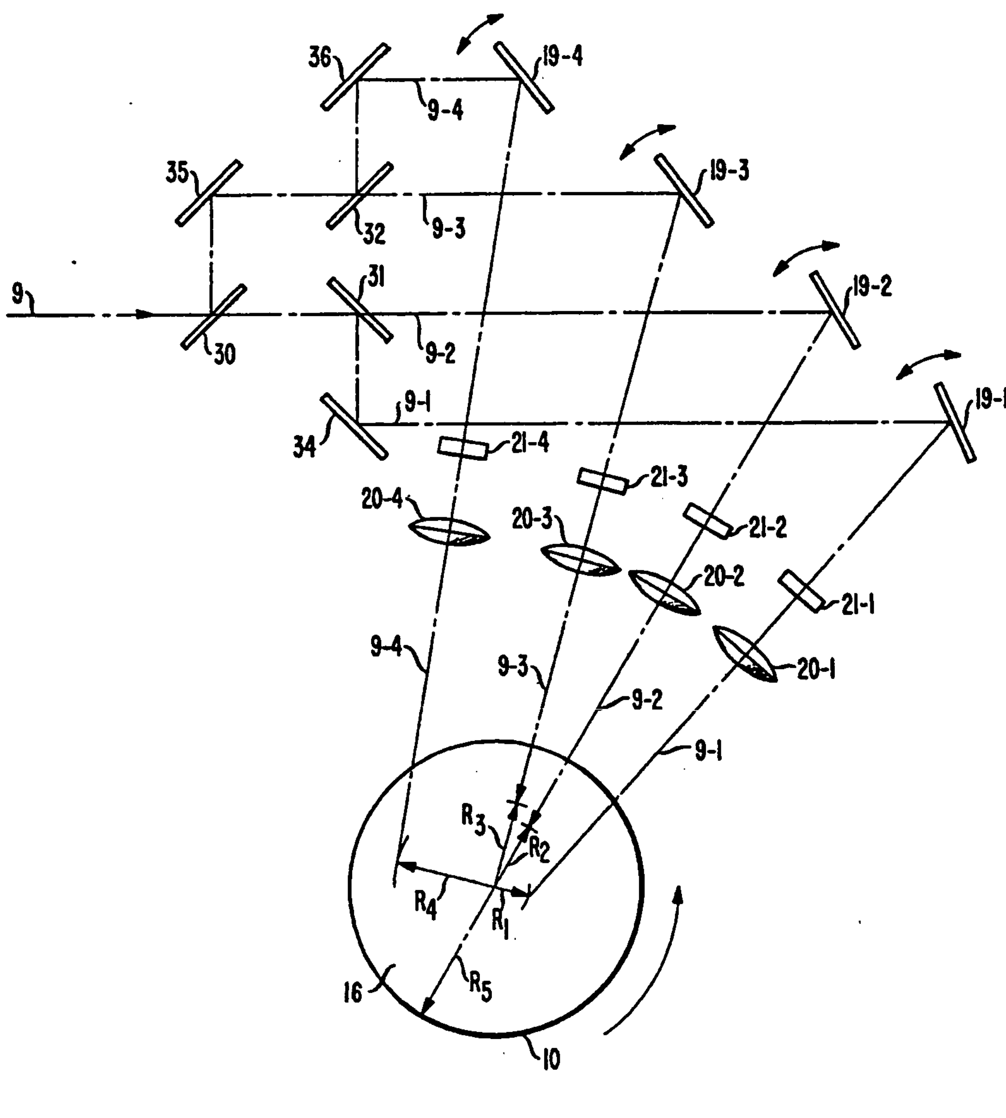


FIG. 3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21-4
21-3
21-2
21-1
20-4
20-3
20-2
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9-4
9-3
9-2
9-1
R3
R2
R4
R1
R5
16
10

FIG. 4

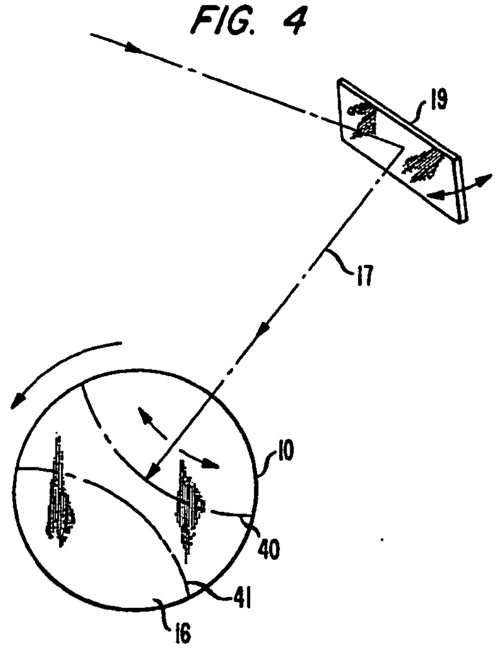

FIG. 5

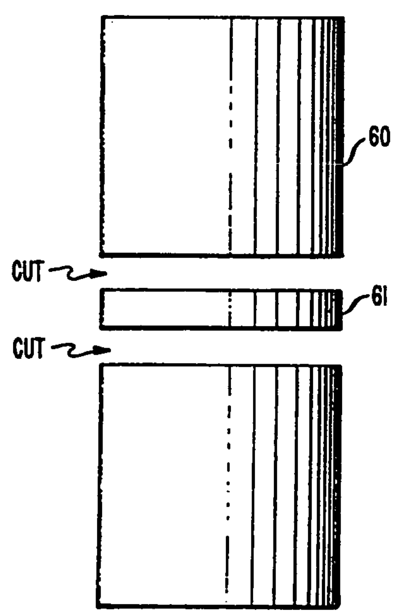

FIG. 6

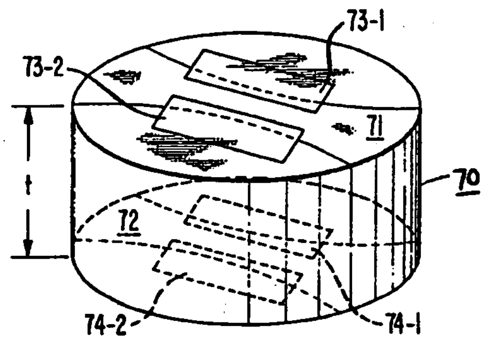

FIG. 7

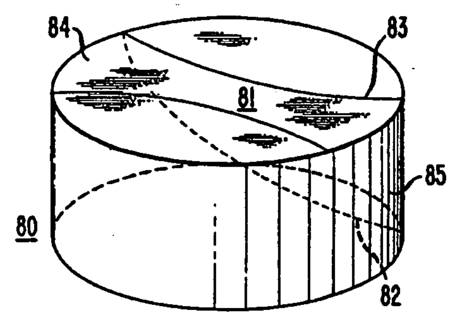

FIG. 8

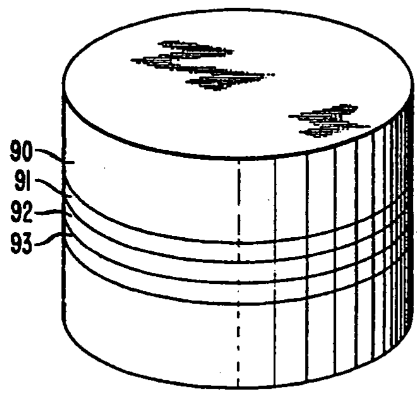

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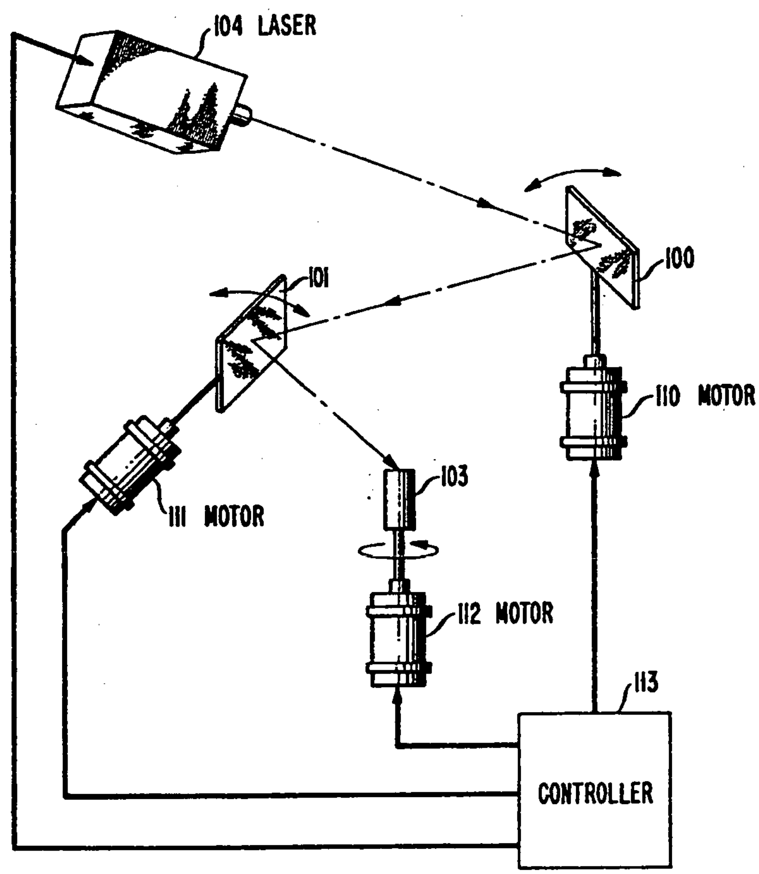
FIG. 9



SPECIFICATION

Optical d vic and preform fabrication

This invention relates to a method of fabricating optical devices and optical fiber preforms.

Various techniques for fabricating integrated optical devices and optical fiber are well known. For example, integrated optical directional couplers are fabricated using conformable mask exposure techniques. To obtain high switching rates, however, very small devices, with spacings of the order of one micron, are required. This, in turn, requires that the masks be made with a high degree of precision in order to obtain these small spacings.

An illustration technique for making optical fiber preforms, from which optical fibers are drawn, is the so-called "Modified Chemical Vapor Deposition" (MCVD) process in which a precursor, in the form of a gas containing glass forming materials and suitable index modifying dopants, is caused to flow into a preform substrate tube wherein it is heated. This causes a layer of glass to be deposited on the inner surface of the tube. The thickness of each deposited layer, and the concentration of dopants within each layer are functions of a number of parameters, all of which must be carefully controlled in order to obtain a fiber with the desired index profile.

Copending G.B. Application No. 8319566 describes the Downward Axial Vapor-phase Deposition (DAVD) method of fabricating soot forms. These forms, when consolidated by heating, produce glass preforms from which optical fibres can be drawn. As noted in the above-cited application, the DAVD process produces a well defined, circular cylindrical soot form with a planar growing surface.

In accordance with the present invention, there is provided a method of fabricating an optical device having a prescribed refractive index profile, said method comprising forming a surface with an initial refractive index formation, and altering said initial refractive index by directing at least one laser beam onto the surface, either as the latter is formed or after it has been formed, so as to selectively evaporate material from a predetermined part of said surface.

The refractive index profile of the growing soot form in the preferred embodiment of the invention is altered by evaporating the index modifying dopants from selected portions of the form. In the illustrative embodiment of the invention described hereinbelow, the growing surface of the soot form is heated locally by a focussed laser beam which "writes" the desired index profile on the growing form. By contr lling th motion of the laser beam and its intensity, any desired ind x profil can be obtained.

For a better understanding of the invention, reference is made to the accompanying drawings, in which:—

FIG. 1 shows an arrangement for controlling the index profil of soot forms in accordance with the pr f rred embodiment of the pres nt inv ntion;

FIG. 2 shows th method of forming a lower index region in a growing soot form;

FIG. 3 shows an arrangement for fabricating more complex index profiles employing a plurality of laser beams;

FIG. 4 shows the fabrication of an optical directional coupler in accordance with the teachings of the invention;

FIG. 5 shows the removal of a chip from a consolidated soot form;

FIGS. 6 and 7 show three dimensional optical circuits;

FIG. 8 shows a multilayered chip in which the refractive indices of adjacent chips are different; and

FIG. 9 shows a generalized arrangement for practicing the invention.

For purposes of illustration and explanation, the DAVD method of fabricating soot forms can be employed, although other forms of VAD systems may be used. In accordance with this method, the form 10 is grown on a silica starting member 11 which is rotated about its vertical axis, as indicated by arrow 12. Means, not shown, are also provided for causing the starting member to move in a downward direction, indicated by arrow 13, as the soot form grows so as to maintain the growing surface 16 at a fixed location relative to the flame 14.

Raw material, such as $SiCl_4$, $GeCl_4$, $POCl_4$, oxygen and hydrogen are fed into a torch 15, which produces fine glass particles by the flame hydrolysis reaction. Initially the particles are deposited onto the end of the starting member 11. As the soot form grows, the glass particles are deposited upon the surface of the downward drawn, axially growing form.

To control the refractive index profile across the growing form, a laser beam 17 is directed as shown in Fig. 1 onto the growing surface 16 of the form. The beam, derived from a suitable source 18 such as a CO_2 laser, is directed onto surface 16 by means of an oscillating mirror 19 that is free to rotate about an axis Z—Z that lies in the plane of the mirror. By means of this motion, the beam can be made to trace a pattern across surface 16. The effect of the beam impinging upon the growing surface is to heat the surface portion being written upon sufficiently to evaporate the index modifying dopant. This results in a change in the refractive index relative to that of the surrounding area. For example, to make an optical fiber preform having a step index profile by the MCVD process, a first plurality of layers having a first refractive index are deposited, followed by a plurality of layers having a second, higher index. The starting tube is then collapsed to form a s lid rod. As is known, slight variation in the dep siti n f succ ssive layers, plus th usual center dip result in a relativ ly irregular index pr fil .

In this embodiment, the pref rm is built up as a s lid of uniform r fractive index comp sition. The lower index cladding is then formed by evaporating some of the index increasing dopant, as shown in FIG. 2. This Figure shows laser beam

17 being directed onto th growing surface 16 of soot form 10 by mirror 19. In particular, the beam is focussed nto a point at a distance R from the center of form 10 by suitable means represented by lens 20. The intensity of the beam, and hence the amount of dopant evaporated, is controlled by means of an attenuator 21 located in the beam path. The width, *w*, of the cladding is controlled by the oscillation of the mirror 19 which causes the beam to scan the interval between R and R + t. As the form rotates, the scanning beam sweeps a circular path to form the cladding of a step index fiber having a core of radius R and a cladding of width *w*.

A more complicated profile, such as quadruple class fiber can be fabricated by the simultaneous use of a plurality of beams and mirrors. Such an arrangement is illustrated in FIG. 3 wherein a laser beam 9 is divided into four beams 9—1, 9—2, 9—3 and 9—4 by means of beam splitters 30, 31 and 32. The beams are directed onto four oscillating mirrors 19—1, 19—2, 19—3 and 19—4 by means of mirrors 34, 35 and 36. The oscillating mirrors, in turn, direct the four beams onto the rotating growing surface 16 of soot form 10. In particular, beam 9—1 is directed onto the soot form so as to scan an annular portion between radii R_1 and R_2. Beam 9—2 scans between radii R_2 and R_3. Beam 9—3 scans between R_3 and R_4, and beam 9—4 scans between R_4 and R_5. The intensity of each beam is controlled, respectively, by an attenuator 21—1, 21—2, 21—3 and 21—4 to produce the desired index profile.

The invention can also be used to fabricate integrated optical devices such as directional couplers, Y junctions and other novel circuit configurations. For example, to form a directional coupler, the laser beam 17 scans a pair of arcs 40 and 41 across the soot form, as shown in FIG. 4. After the desired pattern has been written into the soot form and the latter has been consolidated, the resulting rod is either sliced, if it has the desired physical dimensions, or it can first be drawn to reduce its dimensions and then sliced to obtain the integrated optical chip. This is illustrated in FIG. 5 wherein the consolidated and, if necessary, drawn soot form 60 has been cut and a chip 61 obtained.

It is an advantage of that embodiment that three dimensional optical circuits of various forms can be readily fabricated, as illustrated in FIG. 6, which shows a chip 70 upon which there is formed a first directional coupler 71 and a second directional coupler 72, separated by a thickness *t* of substrate. The two couplers can be the same or different than all others, and each of the four waveguiding strips can be in coupling r lationship with each other. By adding pairs of lectrodes 73—1, 73—2 and 74—1, 74—2 to the chip, a three dimensional switch can be obtained. It is appar nt that this technique can be employed to fabricate other types of thre dimensional circuit configurations. For xample, an internal (i.e., embedded) optical path can be provid d, as indicat d in FIG. 7. For purposes of illustration, FIG. 7 shows a thr e dimensional integrated optical chip 80 having a directional coupler 81 formed on its upper surface 84 and an optical path 82 which runs within the chip substrate from one end of one of the coupler wavepaths 83 to the outer surface 85 of the chip.

FIG. 8 shows a chip 90 in which various layers 91, 92 and 93 have different refractive indices or different compositions, obtained by changing dopants during deposition. These are, in addition, selectively scanned to fabricate optical lasers, amplifiers and LEDs.

FIG. 9 shows a generalized arrangement for practicing the invention comprising a pair of mirrors 100 and 101 supported so as to oscillate about mutually orthogonal axes under the control of motors 110 and 111, respectfully. Also shown is a laser source 104 and a growing soot form 103 that is rotated about its vertical axis by a third motor 112.

The position of the laser beam, the rate at which the soot form rotates and control of the laser output are determined by a controller 113 which, in its most general form, can be a computer programmed to produce the desired index patterns. (Laser beam positioning devices are sold commercially. See, for example, products offered by General Scanning, Inc. of Watertown, Maine.) Depending upon the pattern to be laid down, the process can proceed continuously or operate in an incremental fashion. It should be noted that the DAVD process can be started and stopped without any difficulty so that the beam can be made to scan the soot form surface while the latter is either in motion or at rest. If stopped, the DAVD process can then be restarted and additional soot deposited while the scanning proceeds incrementally or continuously.

The amount of laser power required to evaporate material from the soot form will, of course, depend upon the material involved. For example, germanium doped silica is deposited within the temperature range from 300 to 800 degrees F. However, germanium will evaporate at 900 degrees F. Therefor, in this case, it is obvious that a temperature rise of 900 degrees F is not required.

CLAIMS

1. A method of fabricating an optical device having a prescribed refractive index profile, said method comprising forming a surface with an initial refractive index formation, and altering said initial refractive index by directing at least one laser beam onto the surface, either as the latter is formed or after it has been formed, so as to selectively evap rate mat rial from a predetermined path f said surface.

2. A method according to claim 1, wh rein the initial refractive index formation is of constant refractive index.

3. A method according to claim 2, wherein the optical device is a glass so t form in which th soot, capabl of b ing consolidated into a glass, is

directed onto the growing end surface of the so t form.

4. The method according to claim 3, wherein said soot is directed in a downward direction onto said growing end surface as said form is rotating about an axis that is perpendicular, and wherein said laser beam scans across at least a portion of said end surface.

5. The method according to claim 4, wherein said laser beam scans an annular region over said end surface to form a first region of lower refractive index adjacent a second region of higher refractive index.

6. The method according to claim 3, wherein a plurality of laser beams are directed onto said growing end surface.

7. The method according to claim 6, wherein each beam scans an annular region of different radii.

8. The method according to claim 7, wherein each beam has an intensity which is different from that of the other beams.

9. The method according to claim 3, wherein the soot and the laser beam are directed onto said end surface either sequentially or simultaneously.

10. The method according to claim 3, wherein the refractive index is caused to vary along the direction of form growth and/or in the direction perpendicular to the direction of form growth.

11. The method according to claim 3, wherein the composition of said soot form is varied along the direction of form growth.

12. The method according to claim 1, said regions extend along the surfaces of said portion and within the interior of said portion to form three dimensional optical circuits.

13. A method according to claim 1, wherein the optical device is a three dimensional, integrated optical chip, wherein the initial surface is of constant refractive index formed on a surface, and wherein waveguiding regions of lower refractive index extend along at least two surfaces of said chip.

14. The method according to claim 13, wherein at least one waveguiding region on one of said surfaces is in coupling relationship with at least one waveguiding region on the other of said surfaces.

15. The method according to claim 13, wherein said waveguiding regions form a first optical directional coupler along a first of said surfaces and a second optical directional coupler along a second of said surfaces; and wherein the waveguiding regions of said two directional couplers are in coupling relationship to form a three dimensional coupling array.

16. The method according to claim 15, comprising varying the refractive index along said waveguiding regions as to to control the coupling among said regions.

17. A method of fabricating an optical device, substantially as hereinbefore described with reference to any one of the figures of the accompanying drawing.

18. A three dimensional, integrated optical chip comprising a substrate having a first refractive index; wherein waveguiding regions of lower refractive index extend along a surface of said chip and are embedded within the body of said chip.

19. An optical device prepared by the method according to any one of claims 1 to 17.

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